Neuromorphic Visual TFT with PbS Quantum Dots and Carbon Nanotubes for Neural Network

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1. Abstract

A neuromorphic visual thin-film transistor was developed using quantum dots and carbon nanotubes. The device integrates light sensing, storage, and processing, with PbS quantum dots enhancing the light response and carbon nanotubes ensuring high current transfer characteristics. Under prolonged bias and light exposure, the device demonstrates high stability, with synaptic current significantly increasing with longer exposure, confirming its light-tunable synaptic plasticity. These results indicate new possibilities for enhancing artificial vision systems.

2. Introduction

In the human visual system, light signals are captured by the retina, transmitted to the brain via the optic nerve, and processed and stored at neuronal synapses [1]. This allows for rapid light signal perception and long - term information storage and preprocessing, supporting complex visual cognition. Traditional photodetectors quickly convert light to electrical signals but lack memory due to fast recovery [2], a problem in applications needing continuous monitoring and complex light processing. Neuromorphic visual TFTs, inspired by biology, integrate sensing, storage, and processing, overcoming traditional limitations and offering efficient visual perception. These TFTs mimic biological synapses, incorporating detection, processing, and memory for light signals [3], enabling information storage and preprocessing during light capture, handling complex visual tasks and approaching human visual capabilities [4].

3. Experimental

Fig. 1(a) shows the design of a bottom - gate flexible neuromorphic visual TFT with a channel layer of high - purity semiconductor CNTs. Doping PbS quantum dots (TEM image in Fig. 1(b)) into the polyvinylpyrrolidone (PVP) dielectric layer increases the dielectric layer's capacitance upon light stimulation. This structure enables the device to sense, store, and preprocess light signals, simulating the human eye's role in the nervous system as shown in Fig. 1(c).

4. Results and Discussion

Fig. 2 shows EPSC curves of the TFT under electrical pulses. The device responds more strongly to high - frequency electrical stimulation (Fig. 2(a)) and different durations of electrical stimulation induce varying EPSCs (Fig. 2(b)). Optical pulses show a similar trend. The device also responds more strongly to high - frequency optical signals (Fig. 3(a)), with Fig. 3(b) showing EPSCs for different laser durations at the same intensity. Figure 4 presents STP and LTP curves, demonstrating memory capability. The PPF index indicates short-term memory via increased postsynaptic current amplitude ratios between consecutive peaks. Figure 5 shows PPF index curves under electrical and optical stimulation. Figure 6(a) displays the neuromorphic visual sensor's transfer characteristics (I_{DS} - V_{GS}) under bias stability testing, with the saturation current and transfer curve staying relatively stable as bias duration increases. Figure 6(b) shows that the PPF index remains relatively stable over time, decreasing by about 8% at 1000 s bias duration. Figure 7 presents the LTP / LTD curve, with 100 optical pulses for excitation and 100 electrical pulses for inhibition.

5. Conclusions

A neuromorphic visual thin film transistor based on quantum dots and CNTs have been developed in this study. The device enhanced light response through adding quantum dots in the dielectric layer, with CNTs ensuring satisfied current transfer characteristics. Long-term bias and light exposure tests demonstrated good stability and light-tunable synaptic plasticity. The research highlights the potential of this device for artificial vision systems and provides a new direction for developing efficient neuromorphic devices.

References

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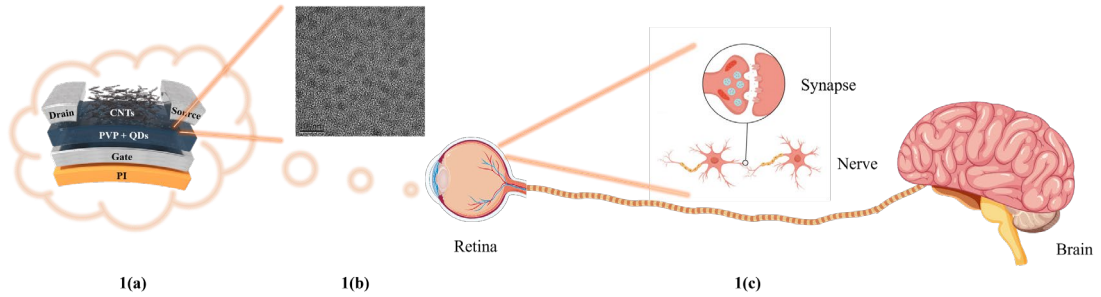

Fig. 1. Schematic diagram of the flexible neuromorphic visual thin film transistor (TFT) structure and human visual neural system. (a) is a schematic diagram of the structure of the neuromorphic visual TFT. (b) shows the Transmission electron microscope (TEM) image of PbS quantum dots. (c) illustrates the human visual neural system.

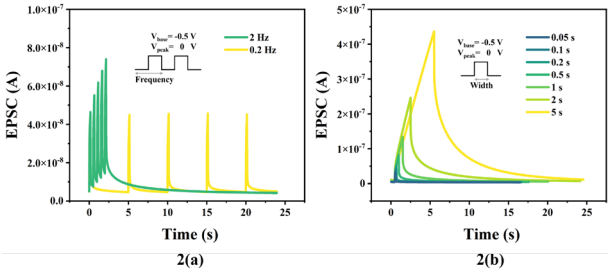

Fig. 2. Electrical pulse synapse test. (a) shows the Excitatory postsynaptic current (EPSC) curves at different frequencies. (b) shows the EPSC curves at different pulse widths.

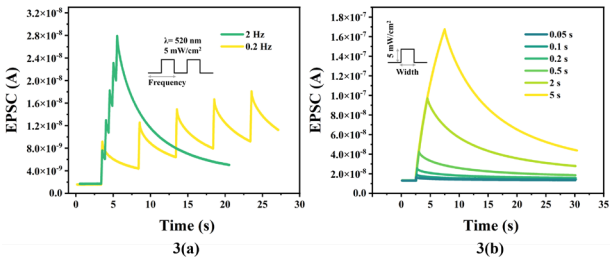

Fig. 3. Optical pulse synapse test. (a) shows the EPSC curves at different frequencies. (b) shows the EPSC curves at different pulse widths.

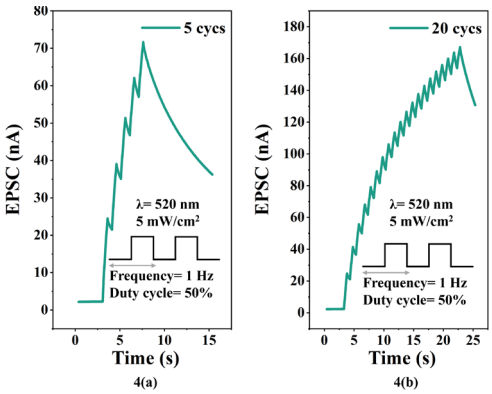

Fig. 4. EPSC curves under different number of laser pluses. (a) shows the short-term plasticity (STP) curve with 5 pulses. (b) presents the long-term plasticity (LTP) curve with 20 pulses.

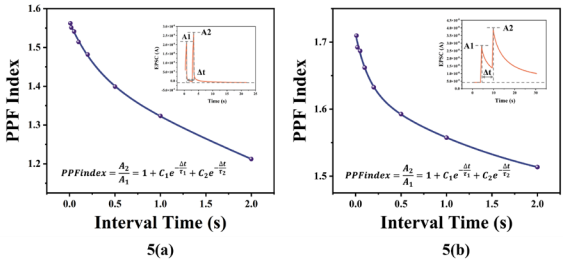

Fig. 5. Paired-pulse facilitation (PPF) index curves. (a) shows the PPF index curve under electrical pulse stimulation. (b) presents the PPF index curve under optical pulse stimulation.

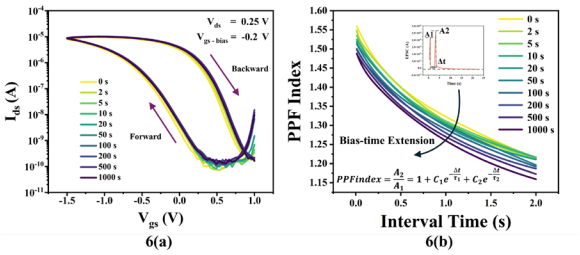

Fig. 6. Device reliability investigation. (a) shows the typical transfer characteristic curves (I_{DS}-V_{GS}) at different bias times. (b) presents the PPF index curves at different bias times.

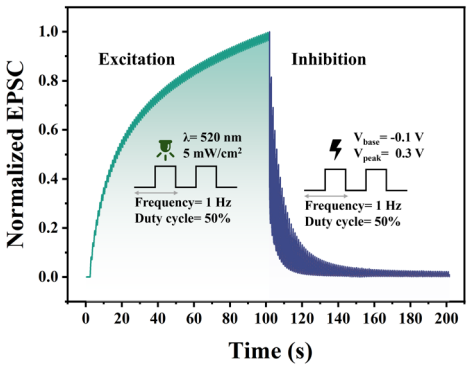

Fig. 7. The long-term potentiation/long-term depression (LTP/LTD) curves using laser pulses for excitation and electrical pulses for inhibition.